SPARK

REPORT

STRATEGIC
PLANNING
FOR
APPLIED
RESEARCH
AND
KNOWLEDGE

Science
Council of
British
Columbia

BIOTECHNOLOGY PLANNING
REPORT FOR
THE SCIENCE COUNCIL
OF BRITISH COLUMBIA

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Biotechnology is defined in this report as the application of biological organisms, systems or processes to manufacturing or service industries. Newer technologies involved are immunology, cell fusion, recombinant DNA, tissue culture and fermentation. Biotechnology is a universal "toolbox" that can be applied to a wide variety of industries and it has global importance.

From the responses to a survey of biotechnology organizations, discussions among the committee members, and an open forum, three applications of biotechnology emerged as being most important to the province - disease control, genetic enhancement and waste management. These are critical to the sectors of forestry, health care, agriculture and aquaculture and are areas in which B.C. has existing strengths. This focus is not intended to limit opportunities in other areas or emerging applications of biotechnology. Rather, it is proposed as a means to priorize those applications which appear to have the greatest impact at this time. As biotechnology develops further in B.C., new priorities may emerge.

A. The following actions are required in these three areas.

1) Disease control - The control of bacterial, viral and pest diseases in forestry, health care, agriculture and aquaculture is required. This involves the development of products such as diagnostics, monoclonal antibody targeted therapeutics, vaccines, specifically designed drugs, immune modulators and biological controls.

2) Genetic enhancement - The application of recombinant DNA technology, cell fusion and tissue culture is required to genetically improve important species in agriculture, aquaculture and forestry. This will result in disease resistant, chemical resistant, faster growing, and otherwise improved organisms that are commercially important.

3) Waste control - Development of waste control processes for agriculture, aquaculture and forestry is required to develop methods for detecting low level toxicants, deodorizing and detoxifying effluents and biological wastes, composting of solid wastes, and in situ detoxifying contaminated soils.

B. Recommendations

1) It is recommended that a long term, consistent commitment be made to funding for biotechnology, as the development of new products and processes can take many years.

2) It is recommended that the Science Council of B.C. seek increased funding for these three strategic biotechnology areas: disease control, genetic enhancement, and waste management. As biotechnology is an emerging industry that can have great impact on areas that are important to the economic development of B.C., it is recommended that the increased funding be made available in staged amounts that reach $30 million per year within five to ten years.

3) It is recommended that the governments enhance strategic research capabilities and training of new students. More scholarships and postgraduate grants should be made available to address the shortage of skilled personnel in the province.

4) It is recommended that the B.C. Science Council and the governments foster further collaborations between the universities and the private sector through student and faculty exchanges, network development, joint ventures and technology transfer.

5) It is recommended by university representatives of the committee that more facilities be constructed for biotechnology. The committee suggests that more efficient, coordinated use of existing facilities is also required.

C. ACTION

The committee recommends that the Science Council of B.C. form a provincial biotechnology steering committee to ensure that the recommendations discussed above are carried out in an efficient, productive manner. This committee would advise the Science Council of B.C. and the government on matters of funding, facilities and personnel. It is also suggested that the committee could engage in the following activities.

1. Collect and priorize input.
2. Direct and focus activities.
3. Supervise funding decisions
4. Supervise task forces in the following areas.
   a) disease control
   b) genetic enhancement
   c) waste management
   d) new technologies and opportunities
5. Maintain a public relations and marketing campaign for dissemination of information.

6. Act as a champion for biotechnology.
7. Coordinate networking, collaborations, and technology transfer.
9. Coordinate interaction with other sectors.
10. Coordinate personnel requirements.

II. INTRODUCTION

The B.C. Science Council began development of a long range plan in the Spring of 1987 with the Council and the provincial government agreeing to the following mission:

> To identify and promote opportunities for the economic development of B.C. by drawing on the scientific and technological community for creative applications of science and technology.

One of the Science Council's objectives involves the development of plans for the application of science and technology in each sector of its activities (Agriculture & Food; Aquatic Resources; Biotechnology; Computers & Computing; Electronics & Communications; Energy; Forestry & Forest Products; Manufacturing & Machinery; Mining, Minerals & Metals). These sector plans are being developed by various committees of the Science Council and are intended to outline the strengths, weaknesses, threats and opportunities for each sector.

The Biotechnology Advisory Committee, consisting of:

Dr. J. Dangerfield (Forintek)
Mr. C. Jensen (Giant Bay Biotech)
Dr. P. Larkin (UBC)
Dr. B. McBride (UBC)
Dr. J. Mueller (B.C. Research)
Dr. T. Owen - Chairman (Helix Biotech)
Dr. J. Schrader (UBC)
Dr. M. Smith (UBC)
Dr. P. Webb (B.C. Research)

gathered information to identify where the applications of biotechnology currently stand in this province and where they should be enhanced in the future. A questionnaire was prepared to obtain infomation on the current state, potential, and recommendations for biotechnology in the province. The questionnaire was sent to 75 individuals identified as being involved in biotechnology research and development in the private and public sectors in B.C. The results, from the 48 respondents, are presented in the "Background" section that follows and in Appendix I.

The strategic plan for research and innovation for biotechnology in B.C., from basic research to final products in the global marketplace, is presented next.

III. BACKGROUND

Time and resources did not permit a comprehensive survey for the preparation of precise quantitative data on biotechnology activities in B.C. However, very clear qualitative information emerged.

For example, a self-evaluation of effectiveness by the responding organizations clearly indicated that improvements are desired. When asked to rate effectiveness on a scale of 0 (not effective) to 10 (very effective), the average response for the public and private sectors were 5.4 and 5.5, respectively. The respondents clearly indicated in their recommendations to the BCSC and the governments that the policies of these administrative bodies would be very crucial to the realization of the goal of increased effectiveness in the area of biotechnology. This certainly provides support for the long-range strategic planning that is currently being undertaken by the Science Council of B.C.

In order of frequency, the responding organizations are involved in research in agriculture, aquaculture, forestry, health care, mining and energy. Although a wide variety of activities was reported, a few key applications of biotechnology cut across all of the sectors above. These are disease control, genetic enhancement, and waste management.

These three areas were selected for a more detailed analysis by the committee. In addition funding, space, and the interaction between the public and private sectors were seen to be important. They are also discussed in more detail, as follows.

IV. OVERALL OBSERVATIONS

People involved in biotechnology in B.C. have the following concerns.

A. Funding

Biotechnology requires a long term commitment as it is an emerging industry that can have a dramatic impact on areas that are critical to the economic development of B.C. The development of new products and processes can take many years. Biotechnology requires further funding in B.C. as there are insufficient facilities and people available to complete the work described below in disease control, genetic enhancement and waste management. More funding for basic research also has a high priority. Although this is definitely beyond the mandate of the BCSC, it should be taken into consideration by the provincial and federal governments since, without basic research, there is no foundation for applied research. One approach would be to define areas of strategic importance and then to fund projects, basic or applied, which will contribute to development of the three key areas of disease control, genetic enhancement and waste management.

There is a need in Canada for more bridge funding between the completion of R&D and the start of manufacturing. Between these two activities lie the problems of scale-up and testing. This work is not innovative enough for funding from the government and is too risky for banks. Venture capitalists will only fund 1% of proposals that they receive and delays in refunding tax credits has seriously hampered the R&D efforts of a number of companies. These problems leave a large gap in the financing that is available in Canada.

To properly finance biotechnology in B.C., it is estimated that additional funding reaching a level of $30 million per year after 5 to 10 years, is required. Further study is needed to provide more detailed projections.

B. Personnel Availability

A lack of trained personnel is a key concern for people involved in biotechnology in B.C. With stable, long-term funding, it is possible to attract top quality scientists to the province. Student grants such as GREAT's and IPDF's are an effective, flexible, cost-efficient means to transfer or develop technology

C. Public and Private Sector Relationships

It is strongly felt that the B.C. Science Council and the governments should continue to foster the development of networks, collaborations, scientist and student exchanges, and technology transfer.

D. Strategic Planning

Strategic planning is also highly recommended to better distribute the available funding, facilities, and personnel. This provides support for the strategic planning process that is now being undertaken by the BCSC.

E. Technology Focus

Since biotechnology has such broad application to the industrial base of B.C., it is necessary to focus on the usefulness of biotechnology to the key industries of the province rather that treat biotechnology as a separate industry. The technologies that have been selected for their strategic importance are disease control, genetic enhancement, and waste management. Each of these is discussed in more detail below.

V. DISEASE CONTROL

A. Introduction

Plants and animals are subject to attack by a variety of disease causing bacteria, fungi, viruses and pests. These organisms cause severe economic loss in the forestry, agriculture and fishing industries, and to the end products produced by these industries. They remain a major factor contributing to human suffering and lost productivity. The advent of modern molecular biology has created powerful new tools which can be applied to the study and resolution of disease. A program in disease control should adopt these new technologies to investigate the biological processes involved in microorganism-host interactions. This in turn will facilitate the development of rapid, sensitive detection systems and methods for preventing disease. It is proposed that microbial disease control be recognized as a strategic area for biotechnological research and development. The major emphasis on fungi, bacteria and viruses rather than insects is a reflection of the distinctly different technologies involved in the study and resolution of diseases caused by these two groups of organisms. In addition, this emphasis will have a major impact on all the important sectors, agriculture, fisheries, forestry and human health.

B. Areas for research and development

The universality of microbial disease implies that research and development strategies should be applied to a wide range of disease problems. The following discussion highlights three exemplary areas:

1) Aquaculture

The viability of the fish farming industry on the B.C. coast is seriously jeopardized by bacterial and viral disease. There is an urgent need to develop appropriate diagnostic kits and to develop effective prophylactic procedures.

2) Forestry

Microbial disease impacts significantly on the viability of the province's coniferous forests. The problem begins with seedlings raised in nurseries, continues throughout the life of the tree, and through to the finished product. There is a pressing need to learn about the basic disease processes in order that effective preventive strategies can be developed. The beneficial and detrimental role of root- associated microorganisms needs to be studied. Pest management through biological controls should be investigated; for

example, incorporation of Bacillus thuringensis toxin genes into plants has been used successfully to control certain pest-associated diseases.

3) Human

Despite great advances, bacterial and viral diseases continue to extract a heavy toll in human suffering and economic loss. There is considerable expertise in B.C. in the study of microbial cell surfaces. This expertise should be strengthened by creating a research emphasis on host-pathogen cell surface. These studies would lead to the development of new diagnostic methods and to the production of vaccines and immune modulators.

There is a theoretical and technological framework which is common to all these diseases and central to the disease control concept enunciated here. This will lead to a fruitful integration of concepts and techniques amongst the various biological systems.

C. Technologies

The following technologies will be common to research in each of the three sectors.

1) Gene Cloning

This is the fundamental development which has created the biotechnology revolution. Genes can be isolated, characterized, modified and transferred. Cloning has created the opportunity to modify specifically an organism's capabilities e.g. make it resistant to a chemical or pathogen.

2) Monoclonal Antibodies

The in vitro production of antibodies which recognize specific antigenic determinants has led to the development of highly specific probes which can be used for a variety of purposes including identification of microorganisms, isolation of antigens and identification of receptor for microbes and microbial toxins.

3) Fermentation

The production of monoclonal antibodies and vaccines will involve growth of both microorganisms and animal cells in large scale culture. State of the art fermentors and associated peripherals will be required.

4) Protein Purification

Both monoclonal antibody and vaccine production will require sophisticated large scale protein purification systems. In many instances these processes will be linked directly to the fermentation units and will involve biological sensing and computer optimized downstream processing systems.

5) Protein Structure-function

In order to design new drugs, the detailed structure of the drug target must be known. This requires x-ray crystallographic analysis of target proteins.

6) Antigen Presentation

The way in which the host interacts with an antigen has a direct bearing on the efficacy of the antigens in stimulating a protective immune response. Considerable effort should be directed to developing appropriate antigen delivery systems.

In terms of manpower it will be necessary to integrate people who have expertise in molecular biology, microbiology, biochemistry, pathology, physiology, virology and mycology.

D. Potential for Technical Development

The commercial "spin off" to be realized will include production and testing of vaccines, production of gene probes or monoclonal antibodies for microbial identification kits and large-scale production of monoclonal antibodies. In addition to production and sales, the accumulated expertise will be transferable to other areas and other diseases. Consequently, there will be opportunity to create technology transfer for an international clientele.

E. Requirements

The amounts of money, the numbers of people and the space required to build an effective disease control research and development program is difficult to determine. The following outlines the minimum requirements. It is predicated on adding onto the existing strengths and facilities in universities, industries and government laboratories. To be effective a minimum of 15 new projects should be initiated. Each should be conducted by a substantial team. An example of such a group would include a senior investigator, a senior research associate, three postdoctoral fellows, three Ph.D. students and three technicians, occupying 2500 sq. ft.

There currently is a critical shortfall in research space in British Columbia. It is proposed that the provincial government give priority to allocating funds for construction of research laboratories.

Salary support could be sought from the federal government through the recently announced Centers of Excellence program and through federal and provincial University-Industry research support programs.

We see this as a multidisciplinary research program incorporating university faculty with scientists from industrial, provincial and federal laboratories.

The program will be complementary to recent provincial initiatives in biotechnology and biomedical research (Wellcome-Fox and the Biomedical Research Centre).

F. Benefits

Benefits accruing from this research initiative will be in the development of new biotechnology-based industries and reduction of economic loss in several sectors. For example, it is estimated that bacterial, fungal and viral diseases annually destroy an amount of wood equivalent to 20% of the total B.C. forestry cut. Even a small reduction in this loss would result in savings of tens of millions of dollars. An indirect benefit will be the building of a provincial biotechnology infrastructure on which a strong biotechnology industry can be built. The integration of university, industrial and government laboratories will ensure that relevant problems are studied and that there is rapid transfer of technology from the laboratory to the marketplace.

VI. GENETIC ENHANCEMENT

A. Introduction

Progress in molecular biology research has led to the development of a technology often referred to as recombinant DNA technology. This includes the process of genetic engineering. Genetic engineering involves the introduction of genes carrying novel traits to organisms which may be totally unrelated to the organism from which the genes were isolated. Thus plants, animals and microbes can be transformed and improved in ways not possible by conventional breeding practices. Most of the progress to date has been made with microbes, however major advances have recently been made in plant systems leading to the development of transgenic plants. The development of new techniques in recombinant DNA technology, cell fusion, plant and animal cloning techniques, and bioprocess engineering encompasses the field of biotechnology.

Genetic engineering of plants requires:

1) A method for introduction of foreign DNA.
2) A tissue culture system which allows for regeneration from single cells.
3) The availability of cloned genes carrying valuable traits.

These techniques, coupled with various regenerative tissue culture systems where appropriate, offer a powerful technique to modify and produce new organisms of commercial importance.

B. Scope Of The Technology

Genetic engineering and recombinant DNA technologies have application to most plant, animal and microorganisms of commercial interest. Recombinant DNA technology and animal cell fusion or hybridoma technology for the production of monoclonal antibodies is having a major impact for example in diagnostic and therapeutic medicine. Genetic engineering technologies are allowing the controlled production of new drugs in commercial quantities such as human insulin, human growth hormone and colony stimulating factors for the health care sector-the first area to see commercialization from biotechnology.

The technology can be broadly applied in animal and plant systems in sectors such as agriculture, aquaculture, forestry, forest products, health

care, mining and waste management. British Columbia has a strong resource base in forestry and the forest products industry is a major component of the province's economy. It is recognized that application of recombinant DNA and tissue culture techniques, along with other biotechnologies, to the resource sector promises to offer major long term economic benefits. Recently, major developments have occurred in the application of recombinant DNA technology in plants and also in the accompanying technology of tissue culture.

Plant tissue culture allows the regeneration of large numbers of plants from a small mass of cells. It also offers the potential to add new, desirable variation into plant genomes. Regeneration follows two paths called organogenesis and embryogenesis. During the process of organogenesis, shoots are produced, separated and rooted. During embryogenesis, whole embryos are produced and grown directly into plants. Cell cultures can be grown in enormous quantities using fermentation technology. Embryogenic cell cultures offer the most powerful and economical way to regenerate plants from tissue culture. Encapsulation of asexual embryos in gels is leading to the development of artificial seeds.

Clonal propagation based on organogenesis has revolutionized large sectors of the ornamental plant industry in the United States, Australia and Europe. It has been possible to extend clonal propagation to the level of cell suspension cultures and this holds the greatest potential for large scale multiplication and automation.

Root culture has been used to produce valuable chemicals although most of the work on plant metabolite production has been done with cell suspension cultures. Developments in this area have not been as rapid as advances in asexual propagation, but if technical barriers can be broken, this field holds great commercial potential, especially in the pharmaceutical industry.

Tissue culture can be used to develop new genotypes by clonal propagation of mutants. Additionally, cultured plant tissues and cells spontaneously produce variants. These "somaclonal" variants add new genetic variation without causing damage to the genome. These approaches have produced disease resistant as well as heavy metal and salt tolerant plants. Disease resistance is an extremely important trait for agricultural, horticultural and forestry applications. Heavy metal and salt tolerance have potential applications in revegetating contaminated and marginal sites with agricultural or forestry species like poplar. Furthermore, herbicide resistant crops have been produced via somaclonal variation. This has great potential

application in agriculture and forestry. The culture of haploid material, like microspores, is particularly valuable in this regard because recessive mutations will be expressed in regenerated plants. Haploid plants have also been extremely useful in standard agricultural breeding programs because they produce pure lines in one step. Desirable variations can also be introduced via protoplast fusion of sexually incompatible species. Cytoplasmic hybrids called cybrids can be obtained following protoplast fusion or fusion of protoplasts with chloroplasts or mitochondria. Furthermore, genes regulating photosynthesis and respiration can be introduced with these organelles.

Genetic engineering offers the prospect of introducing foreign genes for known traits from any organism into plants without otherwise altering the plant genome. A number of techniques have been developed for the introduction of DNA to plants. Most commonly, the bacterium Agrobacterium is used as it has the unique ability to transfer DNA naturally.

Additionally, this system is applicable to a great diversity of plants. It has now been shown to be capable of transforming many agricultural crops, ornamental plants and more recently, forestry species. The application of genetic engineering to plants is therefore limited largely by the availability of suitable tissue culture techniques which enable plants to be regenerated from single cells.

Plants have already been genetically engineered for herbicide resistance and insect resistance and this will undoubtedly have tremendous impact in agriculture in the near future. Other genetically engineered plants under development include those with resistance to fungal diseases and those with altered flower color. Application of these techniques to the introduction of other economically valuable traits will be dependent on a concerted research effort in molecular biology and plant physiology and biochemistry. This is essential in order to understand plant growth and development at the molecular level and allow more complex traits to be manipulated.

Many of the traits which have been introduced into agricultural plants would be of great value in forest species. In particular, resistance to Lepidopteran and Coelopteran insects would greatly reduce timber losses and herbicide resistance would significantly reduce the cost of weed control on reforestation sites. Other applications, such as resistance to other groups of insects require further work but are within grasp and should be well supported. There is a major opportunity for local technology to be applied to

the resource sector, thereby placing British Columbia at the forefront in this area.

C. Current Strengths In B.C.

Research, education and technical training in biotechnology and molecular biology are being carried out at universities, research organizations and technical institutions in British Columbia. There is a demonstrated lack of qualified personnel in British Columbia and Canada both at the post-graduate level and technical levels. To address this problem requires the commitment to strengthen strategic research programs, applied research and technology transfer from which graduates, technical training and experience depends. Prior to 1986 there was one faculty member in the province involved in genetic engineering of plants and only a few in plant molecular biology. This demonstrates the early stages of development of this area in British Columbia and the need to build a critical mass to insure a strong fundamental research base for developing industry.

A number of initiatives are underway to enhance the province's capabilities in biotechnological research. An illustrative listing of research groups involved in biotechnology is appended to this report. See Appendix II.

We need to build on these institutions and initiatives to strengthen manpower, facilities and programs and provide for long term sustained developments.

D. Potential For Technology Development

Major advancements in plant biotechnology appear likely to occur in the following areas:

1) Embryogenic cell suspension and protoplast regeneration systems for major agricultural crops, horticultural crops, and forest species.

2) Fermentation and bioreactor technology for growth of cells for:

a. phytochemical production
b. large scale regeneration via embryogenesis

3) Development of artificial seed technology utilizing embryogenic systems to compete with seed based regeneration systems.

4) Automation technology based on embryogenic regeneration systems.

5) Extension of Agrobacterium-based transformation systems to include major crops and forestry species.

6) Perfection of physical transformation systems like micro-injection, electroinjection and electroporation to achieve high rates of transformation and regeneration of transformed plants.

7) Discovery of new genes.

E. Gaps In Knowledge

There is a general lack of fundamental knowledge of molecular genetics and gene regulation in all areas, especially in higher plants and commercially important forest conifer species where it is essentially nonexistent.

There is a need to understand basic control mechanisms so that "universal" approaches can be taken to regenerate plants from all types of culture systems.

Better understanding of the genetic fidelity of tissue culture plants vs cuttings and parent genotypes is required. Present studies are inadequate. This is especially vital for forestry because of the long testing time. This will require molecular and biochemical as well as cytochemical studies.

F. Economic Benefits

The economic potential that can be obtained from the use of tissue culture and recombinant DNA technologies in various industrial sectors is enormous. If British Columbia is going to diversify its economic base through the application of high technology and the development of a biotechnology industry it needs to strengthen its commitment to strategic research and education in tissue culture and recombinant DNA technologies to insure the development of a strong and continuing scientific infrastructure from which the new developments in technology will come. For example, one reason that the biotechnology industry has centered in California is because of California's strong commitment to education and industrial development.

In the forest products industry, biotechnology can address wood protection, slime control, glucose production, color removal from bleach-plant effluent and anaerobic fermentation of liquid waste. A reasonable expectation from biotechnology on, for example, control of slime in pulp and paper operations is estimated to be over $50 million dollars per year. Transferring genes by recombinant DNA technologies could allow the development of trees with enhanced resistance to disease, frost, drought, herbicides, improved pulping qualities, and improved strength. It is estimated that transferring the Bacillus thuringensis (Bt) toxin gene to Douglas-fir for control of western budworm could give expected potential returns equivalent to losses that occurred in 1987, in British Columbia. The losses were over $150 million.

G. Reasons For Science Council To Support This Area

Tissue culture and recombinant DNA technologies are fundamental to developments in a broad range of industrial sectors. Thus developments in the basic science can be broadly applied in sectors such as agriculture and food, aquaculture, forestry, health care, mining, waste management, etc. It is recognized that the major benefits in the application of biotechnology in Canada are in the resource sector in the longer term, and that human health care is seeing the first benefits from the commercialization of biotechnology.

Science Council must recognize that there is a long road to development of biotechnology concepts-beginning with discoveries in basic science and ending with commercialization. The Council needs to strengthen ways to transfer technology from basic research to industry, and to increase support to the organizations that provide this applied research and technology transfer function.

Both forestry and human health care are major strengths in British Columbia. Enhanced application of biotechnology, specifically tissue culture and recombinant DNA technologies, to these sectors provides a long term and short term strategy to build on strength and be part of what promises to be a major revolution in technological application and the enormous economic potential it promises.

H. Recommendations

1) It is recommended that the B.C. Science Council support tissue culture and recombinant DNA technologies across all industrial sectors with emphasis on forestry, forest products and human health care.

2) That the Council establish an advisory body, a subcommittee of the biotechnology steering committee, to coordinate and integrate initiatives in recombinant DNA research to insure complementary efforts in the province.

3) That the Council provide increased long term funding, such as renewable 5 year grants, to support strategic research .

4) That the Council provide longer term funding for applied research, technology transfer and technical training by providing for Research Scientists, Post-Doctoral Fellowships, technical fellowships, facilities, and increased grants for operating support.

5) That the Council provide long term funding for applied research and commercialization in industry by way of renewable 3 year AGAR grants to industry.

VII. WASTE MANAGEMENT

Definition: Biotechnology in waste management involves the use of micro-organisms and/or their constituents for the transformation, oxidation, removal and/or utilization of waste materials.

A. Biotechnology - A Tool In Waste Management

Waste management in general encompasses many disciplines and technologies and plays a central role in industrialized societies to protect the quality of life and the environment.

Biological waste treatment techniques are well established and represent successful "old biotechnology". "New biotechnology" offers potential for progress in waste management, through microbial strain enhancement and genetic manipulation to allow organisms to break down and detoxify wastes more efficiently or to degrade wastes that hitherto could not be treated biologically.

In the context of biological waste treatment, biotechnology is an interdisciplinary research area that focuses on improvements in microorganisms, processes and systems to achieve the required results. Hence, progress in any of the disciplines: microbiology, genetic engineering, enzyme technology, biochemical engineering, reactor design, bio-sensors and process control is of interest.

For the waste treatment engineer, biotechnology is a tool that has a long, proven track record and is continuously evolving to higher levels of sophistication. Biotechnology is often applied in waste management in combination with other tools; i.e., chemical and physical processes.

Examples of the application of biotechnological approaches to waste management are:

1) Detection of low levels of toxicants in effluents and receiving wastes (e.g., use of monoclonal antibody techniques for monitoring dioxins; use of microbial test systems to measure the toxicity and treatability of a waste).

2) Deodorization of obnoxious gases (e.g., use of bio-filters for oxidation and destruction of odorous substances in emissions from meat rendering plants, gases from municipal and industrial landfills, mushroom substrate composting plants, etc.).

3) Detoxification and treatment of industrial effluents and domestic sewage prior to discharge to receiving waters.

4) Composting of solid wastes and conversion to biological fertilizers (e.g., low and high-rate composting techniques are effective in stabilizing organic, solid wastes and converting them to saleable bio-fertilizers).

5) Catalysis of specific reactions (e.g., oxidation of ammonia to nitrate in effluents from sausage skin manufacturing plants; adsorption of heavy metals in effluents on fungal bio-mass and subsequent removal by filtration; oxidation of thio-salts in mining process effluents to sulfate salts, that can be removed by precipitation).

6) In situ detoxification of soils which have been contaminated with toxic industrial chemicals.

B. Application Of Biological Waste Treatment Technologies In Various Industry Sectors

Biological waste treatment techniques can be applied to all those industry sectors which produce wastes of an organic nature; hence they can impact on most B.C. industry sectors. The following examples are given:

1) Agriculture
Treatment and stabilization of manure.
Composting of solid wastes.
Odour control.

2) Food Processing
Treatment of effluent.
Oxidation of ammonia to nitrate in process solutions.
Anaerobic digestion of solid slurries and high strength wastes.
Bio-conversion of wastes to useful products.

3) Pulp and Paper
Treatment and detoxification of effluents.
Composting of bark and fibrous wastes.

4) Lumber Processing
Microbial degradation and destruction of chlorinated organics (wood preservatives).
Composting of solid wastes.

5) Mining
Oxidation of process chemicals.
Adsorption of metals on fungal biomass and removal by filtration.

6) Aquaculture
Oxidation of ammonia to nitrate in fish hatchery recycle water.
Treatment of hatchery waste waters.
Digestion of solid fish hatchery wastes and conversion to bio-fertilizers.

7) Municipalities
Sewage treatment.
Garbage composting.
Odour control.
Digestion of sludges.

C. Biotechnology Strength In British Columbia

In British Columbia, several groups are active in development and application of biotechnologies to waste treatment. Their activities are diverse and cover topics such as microbiology genetic manipulation of organisms, biochemical engineering and process control. An illustrative listing of research groups involved in Biotechnology is appended to this report. See Appendix III.

D. Benefits From Biotechnology

The benefits of biotechnology to waste treatment are potentially large. In general, biological waste treatment processes are effective, often substantially less expensive than chemical-physical treatment techniques and are applicable to high and low strength wastes.

Biotechnology offers the following short and long-term benefits to waste treatment technology:

1) Short Term
Improved systems.
Enhanced performance.
Wider application.
Lower operating cost.
2) Long Term
Better understanding of biochemical reactions, hence better control.
Selection of organisms capable of catalyzing difficult chemical reactions.
Manipulation of organisms to facilitate reactions, that in natural organisms, are not possible.
Treatment of waste by biological processes that hitherto were not practical or only feasible by more expensive chemical/physical techniques.

E. Potential Biotechnology Developments In Waste Treatment For British Columbia

Among the many potential developments the following stand out:

1) Development of organisms that are capable of degrading and detoxifying polychlorinated organics.

Polychlorinated organics are produced or used by many industrial operations (e.g. pulp mills, lumber mills). They are poorly or non-degradable and persist in the environment. Development of organisms that can metabolize chlorinated organics (e.g. dioxin, polychlorinated bi-phenyls) would allow the application of biological processes to treatment of these wastes.

2) Development and adaptation of anaerobic waste treatment systems.

Anaerobic waste treatment processes have been developed to an advanced state of technology and offer a cost effective alternative to conventional aerobic systems in treatment of high strength, low volume wastes; they yield energy (methane) and valuable biological fertilizers (bio-mass sludge) as by-products.

In British Columbia, the potential exists to adapt anaerobic systems to treatment of pulp mill wastes, food processing effluents, digestion of sludge from municipal waste treatment plants, and treatment of toxic leachates from landfill operations.

3) Thermophilic, high-rate composting of solid wastes.

Thermophilic, high-rate composting technologies offer the potential of stabilizing organic wastes and of converting them to bio-fertilizers. The thermophilic operation ensures pasteurization and destruction of pathogenic organisms. The high-rate systems allow high throughput.

F. Recommendations

It is recommended that the B.C. Science Council support developments in biotechnology that benefit waste management in British Columbia. This support should aim for:

1) Co-ordination and integration of R & D activities that relate to biological waste treatment.

2) Long term financial funding of facilities and staff at centers that engage in biological waste treatment R & D.

3) Short term financial support to industries that endeavor to solve their waste treatment problems by biological processes and which seek the input of biotechnology experts.

G. The following actions are recommended:

1. Biotechnology Advisory Committee On Waste Treatment

Set-up and finance an advisory body on waste treatment, as a subcommittee of the biotechnology steering committee. The waste treatment committee should be made up of representatives from the B.C. Ministry of the Environment, a University, a consulting firm, and each major industry sector (Agriculture, Forestry, Aquaculture, Food Processing).

The mandate of the waste treatment committee should be:

a) To collect and priorize input from various industry sectors regarding waste problems.

b) To disseminate the information to the B.C. Science Council and to all research and consultant groups that work in waste management.

c) To develop and maintain a provincial technical network among parties interested in biological waste treatment (similar to the National Research Council's network "Bio-qual"); organize annual workshops for academia and industry.

d) To advise the B.C. Science Council on activities, issues and support needs in the biological waste treatment area.

2. Long Term Support For R & D Staff

Although various centers are active in waste treatment biotechnology, they are understaffed and underfunded. It is recommended that the B.C. Science Council begin funding immediately:

a) Three full time biotechnologists for research and development.
b) Six Ph.D. fellows (3 year terms).

As local expertise grows, an increasing number of staff should be funded, with the selection and numbers to be determined by the waste treatment advisory committee. The selection of research priorities and the allocation of biotechnologist and Ph.D. fellows to individual centers may be delegated to this committee.

3. Short Term Support To Industries

Once the various biotechnology research centers have been strengthened by the new staff, the use of this expertise by the industry should be encouraged.

It is recommended that funding be allocated annually to biotechnology proposals that come from industry and address biological waste treatment problems. Joint proposals from industry and academia should be given preference.

4. Support Of R & D Facilities

Concurrent with support for R & D staff, it is recommended that the B.C. Science Council allocate funding to facility support. Allocation and distribution to the various groups may be delegated to the Advisory Committee.

5. Support For The Advisory Committee

In order to assist the Advisory Committee in discharging its functions, financial support is recommended to defray the cost for secretarial assistance, mailing, travel, etc.

VIII. REQUIREMENTS

A. Personnel

Innovative application of new techniques and inventions in the biotechnology area demands a constant flow of information between industry and individuals carrying out basic research. Rapid deployment of new information has often been critical to commercial success. Because breakthroughs at the bench are now applied so rapidly, traditional means of technology transfer and training tend to be inefficient. The best way by far, for a company to put a new technology to work, is to hire the innovator or scientist working in basic research in the same area.

The best scientists, working at the cutting-edge of biotechnology research, are unlikely to be recruitable to small biotechnology firms. There is little prospect that after development of their original concept, they would be able to return to the analysis of another basic research problem. This means that truly innovative scientists at their forefront of technology are unlikely to be attracted to positions in smaller companies where they could oversee the development of their ideas.

One solution to this problem is for the provision of a government funded career structure that allows scientists in basic research institutions to follow their innovations into industry without losing the opportunity to return to basic research when their mission industry is fulfilled. This mechanism would involve a system of renewable five year fellowships tenable at research institutes, universities and private companies. Awards and renewal would involve a rigorous peer-reviewed system. Productive individuals could look forward to a lifetime career in aspects of basic research and its applications. When engaged in development work in industry, fellows would be wholly or partly paid by that industry. A return to basic research, where their salary was funded entirely by the fellowship system, would be through a mechanism of a guaranteed 3 years funding. At this point a peer review of productivity and suitability for continued funding would be made. If the decision on the suitability for further support in basic research was unfavorable, the fellow would be given 2 years notice to allow him to find alternative employment. Current research funding places a great deal of emphasis on university based careers which necessarily involve a commitment to teaching and other duties in addition to research.

B. Facilities

As described previously in the sections on disease control, genetic enhancement and waste control, a need is seen for more space and facilities to accommodate essential activities in biotechnology research and development. In addition to new facilities, it is necessary to better manage the current available space. The amount of space presently available, and the space required for the future, need to be defined. The steering committee, discussed below, could take on this responsibility.

C. Funding

Additional funding is required for biotechnology. This would have to come in staged amounts from a combination of public and private sources. Again, the steering committee described below, would have the responsibility to provide a budget for the required funding and to determine its sources. It is estimated that funding should initially be increased to $10 million per year over five years. Once the infrastructure, staff, facilities and priorities are in place, funding should be increased to $30 million per year over the next five years. Further study is required to more precisely define the requirements and projections.

D. Coordination

To manage the requirements described above, it is recommended that the B.C. Science Council establish a provincial biotechnology steering committee. This committee would advise the Science Council of B.C. and the government on matters of funding, facilities and personnel. It is also suggested that the committee could engage in the following activities.

1. Collect and priorize input.
2. Direct and focus activities.
3. Supervise funding decisions
4. Supervise task forces in the following areas.
   a) disease control
   b) genetic enhancement
   c) waste management
   d) new technologies and opportunities
5. Maintain a public relations and marketing campaign for dissemination of information.
6. Act as a champion for biotechnology.
7. Coordinate networking, collaborations, and technology transfer.

9. Coordinate interaction with other sectors.
10. Coordinate personnel requirements.

IX. RECOMMENDATIONS

1) It is recommended that a long term commitment be made to funding for biotechnology, as the development of new products and processes can take many years.

2) It is recommended that the Science Council of B.C. seek increased funding for these three strategic biotechnology areas: disease control, genetic enhancement and waste management. As biotechnology is an emerging industry that can have great impact on areas that are important to the economic development of B.C., it is recommended that the increased funding be made available in staged amounts that reach $30 million per year within five to ten years.

3) It is recommended that the governments enhance strategic research capabilities and training of new students. More scholarships and postgraduate grants should be made available to address the shortage of skilled personnel in the province.

4) It is recommended that the B.C. Science Council and the governments foster further collaborations between the universities and the private sector through student and faculty exchanges, network development, joint ventures and technology transfer.

5) It is recommended by university representatives of the committee that more facilities be constructed for biotechnology. The committee suggests that more efficient, coordinated use of existing facilities is also required.

C. ACTION

The committee recommends that the Science Council of B.C. form a provincial biotechnology steering committee to ensure that the recommendations discussed above are carried out in an efficient, productive manner.

Appendix I

Survey Results

There are nearly 500 people involved in biotechnology activities in the B.C. organizations represented by the 48 people who responded to the survey. These are split almost evenly between the private and public sectors. As the question was general about the number of people involved in biotechnology activities, further study would be required to determine if these estimates were inflated by including non-technical people such as secretarial staff in an organization that is totally dedicated to biotech activities, e.g., the biotechnology centre at UBC and the ecology group at SFU. In addition, the people listed may not be totally involved in biotechnology but rather, be spending only a portion of their time on such activities. Despite these qualifiers, it is still apparent that a large number of individuals are involved in biotechnology activities in B.C. If further investigation was undertaken to solicit data from the non-responding organizations, the numbers stated would probably be at least confirmed, if not increased.

Currently, over $12 million per year being spent on biotechnology activities in the B.C. organizations represented by the 48 people who responded to the survey. For the same reasons given above, these numbers may be inflated, but considerable effort was expended to confirm those that seemed questionable and appropriate corrections were made. Further study would be required to provide a truly accurate figure as different organizations may be reporting different things e.g., wages only, wages plus overheads, total costs, etc. Regardless, considerable expenditures are being made on biotechnology in B.C.

Appendix II

Genetic Enhancement - Current Strengths In B.C.

1. U.B.C. Biotechnology Laboratory

Basic research on Recombinant DNA, molecular genetics, gene regulation and tissue culture technologies.

2. U.B.C. The Biomedical Research Center

Recombinant DNA, protein sequencing and synthesis, tissue culture and monoclonal antibody technologies.

3. U.B.C. Microbiology

Recombinant DNA technologies applied to microbes and enzyme production.

4. U.B.C. Agriculture (Botany)

Tissue culture- conifers.

5. U.B.C. Plant Science

Tissue culture- ornamentals, agricultural crops.

6. U.B.C. Animal Science

Livestock and other animals.

7. U.B.C. Forest Science

Tissue culture- conifers.

8. U.B.C. Food Science

Cell culture.

9. S.F.U. Biological Sciences

Tissue culture- conifers, ornamentals, agricultural and insect.

10. S.F.U. Pest Management Institute

Recombinant DNA (nematode), biocontrol.

11. U. Vic. Forest Biology

Developing tissue culture and recombinant DNA research capability in forest conifer regeneration.

12. BCIT Bioengineering Sciences

Tissue culture & Biotechnology teaching at technical level.

13. BCR Forest Biotechnology Centre

Recombinant DNA and tissue culture technologies in conifers, other plants, and microbes.

14. Forintek

Biotechnology lab in Ottawa.
Biocontrol, sap stain, decay fungus.
Vancouver base.

15. Paprican

Tissue culture in Pt. Claire Quebec.
Vancouver lab.

16. Agriculture Canada

Vancouver Lab.
Recombinant DNA and tissue culture.
Agricultural crops, viruses.

17. Canadian Forestry Service

PFRC.
Recombinant DNA (conifers).

18. Industry

Tissue culture capabilities, little recombinant DNA technology.

Appendix III

Waste Management - Biotechnology Strength In British Columbia

1. Microbiology and Biochemistry Departments At The Universities Of British Columbia, Victoria and Simon Fraser

Selection and genetic manipulation of microorganisms.
Gene sequencing.
Enzymatic pathways.
Gene transfer and expression.

2. Civil Engineering. U.B.C.

Process design and control.
Development of novel sewage treatment systems.

3. Chemical Engineering. U.B.C.

Biochemical engineering.
System engineering (anaerobic digestion of food wastes).

4. Bio-Resource Engineering. U.B.C.

Biochemical engineering.
Process control.
Down stream processing (agricultural waste treatment).

5. Food Science. U.B.C.

Microbiology.
Fermentation technology (thermophilic waste treatment).

6. B.C. Research And Various Consultants

Technology transfer to industry (industrial waste treatment).
Utilization of wastes.
Feasibility studies (biological approaches to waste treatment).

Appendix IV

Disease Control - Current Strengths In B.C.

1. UBC Department of Microbiology

Monoclonal antibodies, Recombinant DNA, pathogenic bacteria

2. UBC Division of Infectious Disease

Pathogenic bacteria

3. UBC Department of Paediatrics

Recombinant DNA, pathogenic viruses

5. UBC Department of Medical Genetics

Monoclonal antibodies, Recombinant DNA

6. U. of Victoria Department of Microbiology and Biochemistry

Monoclonal antibodies, Recombinant DNA, fish pathogens

7. UBC Department of Plant Science

Plant pathogens

8. UBC Department of Botany

Recombinant plant pathogens

9. UBC Department of Pathology

Viruses

10. Quadra Logic Technologies (Vancouver, BC)

Diagnostics and monoclonal antibodies

11. Helix Biotech (Richmond, BC)

Diagnostics

12. UBC Biotechnology Laboratory

Recombinant DNA

13. Fisheries Research Station (Nanaimo, BC)

Fish pathogens

14. Agriculture Canada

Plant viruses

15. B.C. Research Council

Tree pathogens, Recombinant DNA

SUMMARY OF RECOMMENDATIONS

FROM ALL SECTORS

AGRICULTURE AND FOOD PROCESSING

PRIMARY AGRICULTURE
- ROLE OF AGRICULTURE CANADA
- VERY SMALL AVAILABLE LAND BASE

SECONDARY MANUFACTURE
- POTENTIAL GROWTH AREA

FOOD PROCESSING
- POTENTIAL GROWTH AREA

RECOMMENDATIONS

- INTERFACE WITH BIOTECHNOLOGY
  - DISEASE CONTROL
  - GENETICS
  - WASTE MANAGEMENT
- VALUE ADDED
  - FOOD PROCESSING
- INCREASE PRODUCTIVITY
- INCREASE INDUSTRY INVOLVEMENT
  - CO-OPERATIVE RESEARCH

AGRICULTURE AND FOOD PROCESSING

RECOMMENDATIONS (CONT'D.)

- FUNDING FOR SECONDARY MANUFACTURE, FOOD PROCESSING
- RESEARCH ORGANIZATIONS STAFFING AND EQUIPMENT
- GENERAL AWARENESS
- TECHNOLOGY TRANSFER

AQUATIC RESOURCES

$750M INDUSTRY

AQUACULTURE - HIGH GROWTH
- SCIENCE ISSUES

RECOMMENDATIONS

- WATER QUALITY
  - SPECIFIC CONTAMINANTS
  - AQUACULTURE
- AQUATIC INSTRUMENTS AND DEVICES
  - INTERFACE WITH SECTOR
  - GROWTH AREA
- FISH HARVESTING
  - GOVERNMENT AND SOCIAL POLICIES
  - IMPROVEMENTS POSSIBLE
  - SHIP/SHORE COMMUNICATION

AQUATIC RESOURCES

RECOMMENDATIONS (CONT'D.)

- FISH PROCESSING
  - NEW PRODUCTS
  - BY-PRODUCTS
  - QUALITY
  - PACKAGING
- AQUACULTURE
  - INTERFACE WITH BIOTECHNOLOGY
    - DISEASE CONTROL
    - NUTRITION
    - GENETICS
    - WASTE MANAGEMENT
  - NETWORK OF EXCELLENCE

BIOTECHNOLOGY

EMERGING INDUSTRY - $12M

IMPACTS ON MANY SECTORS - FORESTS
- AGRICULTURE
- AQUACULTURE
- HEALTH
- WASTE MANAGEMENT
- MINING

NEED FOR STRATEGIC PLANNING, CO-ORDINATION

RECOMMENDATIONS

- FOCUS ON
  - DISEASE CONTROL
  - GENETIC IMPROVEMENT
  - WASTE MANAGEMENT

- STRATEGIC PLANNING - USE OF EXISTING COMMITTEE

- LONG TERM COMMITMENT OF FUNDING

- RAISE FUNDING FROM $10M TO $30M - 5-10 YEARS

BIOTECHNOLOGY

RECOMMENDATIONS (CONT'D.)

- STRATEGIC RESEARCH, TRAINING, SCHOLARSHIPS
- INDUSTRY/UNIVERSITIES INTERACTION
- REVIEW FACILITIES NEEDS AND CO-ORDINATION

ENERGY

MAJOR RESOURCE OF PROVINCE

DEPENDENCE OF OTHER RESOURCE SECTORS

OIL - IMPORT TO B.C.

NATURAL GAS SURPLUS

RECOMMENDATIONS

- OIL & GAS
  - DEVELOP UNDERSEA ROBOTICS
  - PREPARE FOR SWITCH AWAY FROM OIL
  - NATURAL GAS DIESEL ENGINE CONVERSION
- COAL
  - DEVELOP CAPABILITY TO ANALYZE COALS
  - BENEFICIATION & TRANSPORTATION
  - ALTERNATIVE USES

ENERGY

RECOMMENDATIONS (CONT'D.)

- WOOD RESIDUE AND BIOMASS
  - CONTINUE DEVELOPMENTS - METHANOL, ETHANOL
- OTHERS
  - HYDROGEN
  - FUEL CELL

SCIENCE & TECHNOLOGY ENERGY FOCUS

- CENTRE FOR ENERGY STUDIES
- BUILD EXPERTISE
- UNDERTAKE TESTS
- NATURAL GAS
- LONGER TERM ITEMS

FORESTS AND FOREST PRODUCTS

GROWTH AREA

MOVING TO VALUE ADDED PRODUCTS

RESOURCE DIMINISHING AND MORE EXPENSIVE

WORLD-WIDE COMPETITION

DEPENDENCE ON SCIENCE & TECHNOLOGY

ADVANCED MACHINERY AND SYSTEMS

PEOPLE NEEDS

RECOMMENDATIONS

- OVERALL CO-ORDINATION FOR SCIENCE AND TECHNOLOGY
- ADD VALUE
- IMPROVE PRODUCTION FOR RESOURCE

FORESTS AND FOREST PRODUCTS

RECOMMENDATIONS (CONT'D.)

- RAISE TECHNOLOGICAL AWARENESS AND COMPETENCE
  - RESEARCHERS
  - 'RECEPTORS'

- TECHNOLOGY TRANSFER

- USE OF ADVANCED SYSTEMS, TECHNOLOGIES AND MACHINERY

INFORMATION TECHNOLOGY

$1 BILLION INDUSTRY

11,500 PEOPLE

25%-50% ANNUAL GROWTH

RESOURCE INDUSTRIES/INFORMATION TECHNOLOGY

PEOPLE NEEDS

CO-ORDINATED ACTIONS

RECOMMENDATIONS

- ENHANCE RESOURCE INDUSTRIES BY ENHANCING THE INFORMATION TECHNOLOGY INDUSTRIES
- COMMIT TO INFORMATION TECHNOLOGY
- MARKETING, MANAGEMENT, TECHNICAL PEOPLE
- CO-ORDINATION AND PLANNING ROLE
- INFRASTRUCTURE AND SUPPORT

MANUFACTURING

IMPORTANCE TO PROVINCE

4,000 COMPANIES - 40 LARGE

LACK OF TRAINING

DIFFICULTIES OF LOCATING PARTNERS

TECHNOLOGY TRANSFER - SMALL COMPANIES

RECOMMENDATIONS

- STRATEGIC PLAN - 'CHAMPION'
- BIOMEDICAL DEVICES
- EDUCATION AND TRAINING
- TECHNOLOGY CENTRE
- RESOURCE INDUSTRIES - ROBOTICS
- NETWORKING
- CAD/CAM
- FUNDING

MINING, MINERALS, METALS

NEEDS

- INDUSTRY INVOLVEMENT
- NATIONAL CO-ORDINATION
- FOCUS ON R&D
- RAISING AWARENESS

RECOMMENDATIONS

- R&D CO-ORDINATOR FOCUSSED ON B.C. NEEDS, NATIONAL INTERFACE

- INDUSTRY CHAIRS - ADVANCED MATERIALS

- CENTRES OF EXCELLENCE:

  - ADVANCED MATERIALS
  - INDUSTRIAL MINERALS
  - GEOLOGICAL EXPLORATION
  - RARE & PRECIOUS METALS

EMERGING THEMES

- BUILD ON EXISTING COMPANIES, ORGANIZATIONS AND INDIVIDUALS
- ORGANIZED STIMULATION OF INTERACTION AND PLANNING WITHIN AND BETWEEN SECTORS
- RESOURCE INDUSTRY FOCUSSED, TECHNOLOGY DRIVEN CENTRES OF EXCELLENCE
- VALUE ADDED PRODUCTS FROM RESOURCES USING TECHNOLOGY DEVELOPED IN B.C.
- DEVELOP THE MARKETING, MANAGEMENT AND TECHNICAL TALENTS OF OUR PEOPLE
- EFFECTIVE USE OF SIGNIFICANTLY MORE R&D SPENDING

Science Council of British Columbia

Helping Make Tomorrow Happen in B.C.